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DATE 4 January 1965

REPORT NO. NAEC-AML-2107

VAPOR LUBRICATION OF HIGH SPEED BALL BEARINGS

PROBLEM ASSIGNMENT NO. C 03 RMA 42-14 UNDER BUREAU OF NAVAL WEAPONS
WEPTASK RRMA 04 014/200 1/R001 07 01

A. OBJECT

To investigate the lubricant properties of reaction products resulting from the interaction of vapors generated by volatile compounds and the constituents of the metal bearing surfaces.

B. DETAILS

1. Mechanism for Vapor Lubrication

Several possibilities for the process of vapor lubrication can be projected, e.g.:

(a) Decomposition of vapor at elevated temperature yielding a liquid fraction.

(b) Formation of solids produced by chemical reaction between metal and vapor.

(c) Physical adsorption of vapors on metal surfaces.

It is considered that the chemical composition of the volatile solids as well as the alloying elements of the bearing will determine the specific reaction category. For example, amine carbamates have been shown to undergo the following thermal decomposition:

$$\underset{\substack{\text{Amine Carbamate}\\ \text{(Solid)}}}{R-\underset{\substack{|\\ H}}{N}-\overset{\substack{O\\ \|}}{C}-OH_3NR} \longrightarrow \underset{\substack{\text{Amine}\\ \text{(Liquid)}}}{2RNH_2} + \underset{\substack{\text{Carbon Dioxide}\\ \text{(Gas)}}}{CO_2}$$

The liquid amine may function as a fluid lubricant exhibiting hydrodynamic behavior. The results for carbamates prepared from amines of low boiling points as shown in Plate 1 tend to corroborate this estimate of the lubrication process.

The decomposition of amine dithiocarbamates and resulting products require different interpretation of the lubrication phenomena. The decomposition of amine dithiocarbamates exposed to elevated temperatures can be described on the basis of the following reactions:

$$(1)\quad R\text{-}\underset{H}{N}\text{-}\overset{S}{\overset{\|}{C}}\text{-}SH_3NR \longrightarrow R\text{-}\underset{H}{N}\text{-}\overset{S}{\overset{\|}{C}}\text{-}\underset{H}{N}\text{-}R + H_2S$$

Amine Dithiocarbamate (Solid) → Dithioalkylurea (Solid) + Hydrogen Sulfide

$$(2)\quad R\text{-}\underset{H}{N}\text{-}\overset{S}{\overset{\|}{C}}\text{-}SH_3NR \longrightarrow RNCS + H_2S + RNH_2$$

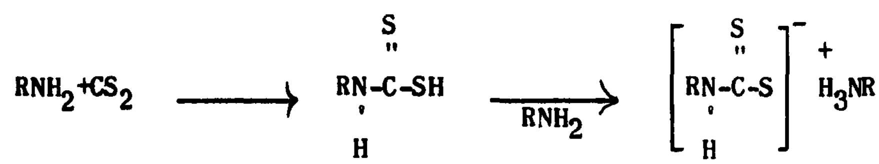
Amine Dithiocarbamate (Solid) → Alkyl Isothiocyanate (High Boiling Liquid) + Hydrogen Sulfide (Gas) + Amine (Liquid)

A film of metallic sulfide was detected on the surface of the test bearing after completion of tests using allylamine dithiocarbamate as the lubricant. It is considered that hydrogen sulfide released during the thermal decomposition of the amine dithiocarbamate initiated the formation of the solid inorganic sulfide compound. In addition the isothiocyanates formed in the second reaction are high boiling liquids and may also contribute to the lubrication process.

The mechanism of physical adsorption is also considered to be a significant factor in the vapor lubrication process for certain compounds. Morpholine carbamate, for example, exhibits a reduced lubricating effect as the test temperature for bearing assemblies is reduced below 150°F. It should be noted however, that the number of test runs were limited and additional low temperature tests are currently underway for morpholine carbamate and other volatile compounds.

2. Experimental

Experiments described in Report Nos. NAMC-AML-1532 and NAMC-AML-1758 showed that effective lubrication for high speed ball bearings is provided by several types of organic compounds. The compounds included amines, amine carbamates, aromatic hydrocarbons and terpenes. The apparatus used in the vapor lubrication experiments was described in Report No. NAMC-AML-1532. Laboratory work has continued in order to cover the investigation of other compounds (amine dithiocarbamates, chlorinated aromatic amines, bromocamphor) and factors critical in the vapor lubrication process. The chemical structures covering typical compounds used in the vapor lubrication studies are shown in Plate 2. The amine dithiocarbamates were prepared by reacting carbon disulfide with an amine compound, e.g.:



The reaction is analogous to the reaction of CO_2 to produce an amine carbamate. However, a major difference between the two reaction products is shown by thermal decomposition. The amine dithiocarbamates do not yield the initial reactants while amine carbamates produce the liquid amine plus CO_2.

Table 1 shows the lubricant performance properties of 14 different organic compounds using nitrogen carrier gas. Chromium alloy bearings having carbon steel retainer components were selected as the test specimens. Additional studies were conducted using argon, helium, oxygen and carbon dioxide as carrier gases for camphor, naphthalene morpholine carbamate, cyclohexylamine carbamate, and dicyclohexylamine carbamate to determine the effect of carrier gas properties on vapor lubrication. The results of initial work covering the effect of carrier gas is shown in Table 2.

C. RESULTS

1. Amine dithiocarbamates prepared from amine compounds of low boiling point produced extended running times, however, the amine dithiocarbamates prepared from morpholine were ineffective as a vapor lubricant. It is considered that this effect which is significantly different for amine carbamates as shown in Plate 1 may be associated with lower volatility of the amine dithiocarbamates.

2. High temperature performance tests conducted under conditions of continuous running for p-dichlorobenzene resulted in running time increases in the range of 500%. The reduced running time under cycling conditions of operation may be caused by the corrosion products formed in large quantities on the test bearing surfaces during periods of shutdown.

3. Dichloroaniline and bromocamphor produced short running times.

4. Experiments conducted to date show that reduced lubricant properties are shown for camphor, naphthalene, morpholine carbamate, cyclohexylamine carbamate and dicyclohexylamine carbamate when substituting oxygen, carbon dioxide, argon and helium for nitrogen carrier gas.

D. ACTION

The means of bringing the volatile compound to the test bearing has been found to be a major factor in total running times. Accordingly, laboratory tests are underway to determine the optimum means of delivering the lubricating vapors. An initial modification for the dispersion of volatile solids consisted of providing alternate layers of the volatile compound and glass wool. This approach has provided for a 400% increase in performance using naphthalene carried in nitrogen. In view of this finding, efforts will be concentrated in studying this variable. Additional work will encompass: carrier gas variables, temperature effects and methods for producing self contained vapor lubricated bearings.

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List of Tables:

TABLE 1

RESULTS OF VAPOR LUBRICATION EXPERIMENTS

Apparatus: High Speed, High Temperature Bearing Test Apparatus

Speed: 10,000 RPM

Bearing Specimen: 204 Size Ball Bearing, Balls and Races: AISI 52100
Retainer: AISI C1010

Carrier Gas: Nitrogen (Flow Rate - 0.08 cu. ft./min.)

Test Temperature: 250°F

Organic Solid	Running Time Hours
Isopropylamine Dithiocarbamate	112, 333
Morpholine Dithiocarbamate	0.1, 0.1
Allylamine Dithiocarbamate	278, 467
n-Butylamine Dithiocarbamate	62, 47
n-Butylamine Carbamate	0.4, 0.5
Allylamine Carbamate	34, 10+
Isopropylamine Carbamate	0.10
Terpinol	0.2, 0.1
2,5 Dichloroaniline	6, 25
3,5 Dichloroaniline	0.7
p-Dichlorobenzene[1]	21, 28, 20
p-Dichlorobenzene[2]	216, 170
Bromocamphor	10

NOTE: 1 - Intermittent Running

2 - Continuous Running

TABLE 2

EFFECT OF CARRIER GAS ON VAPOR LUBRICATION

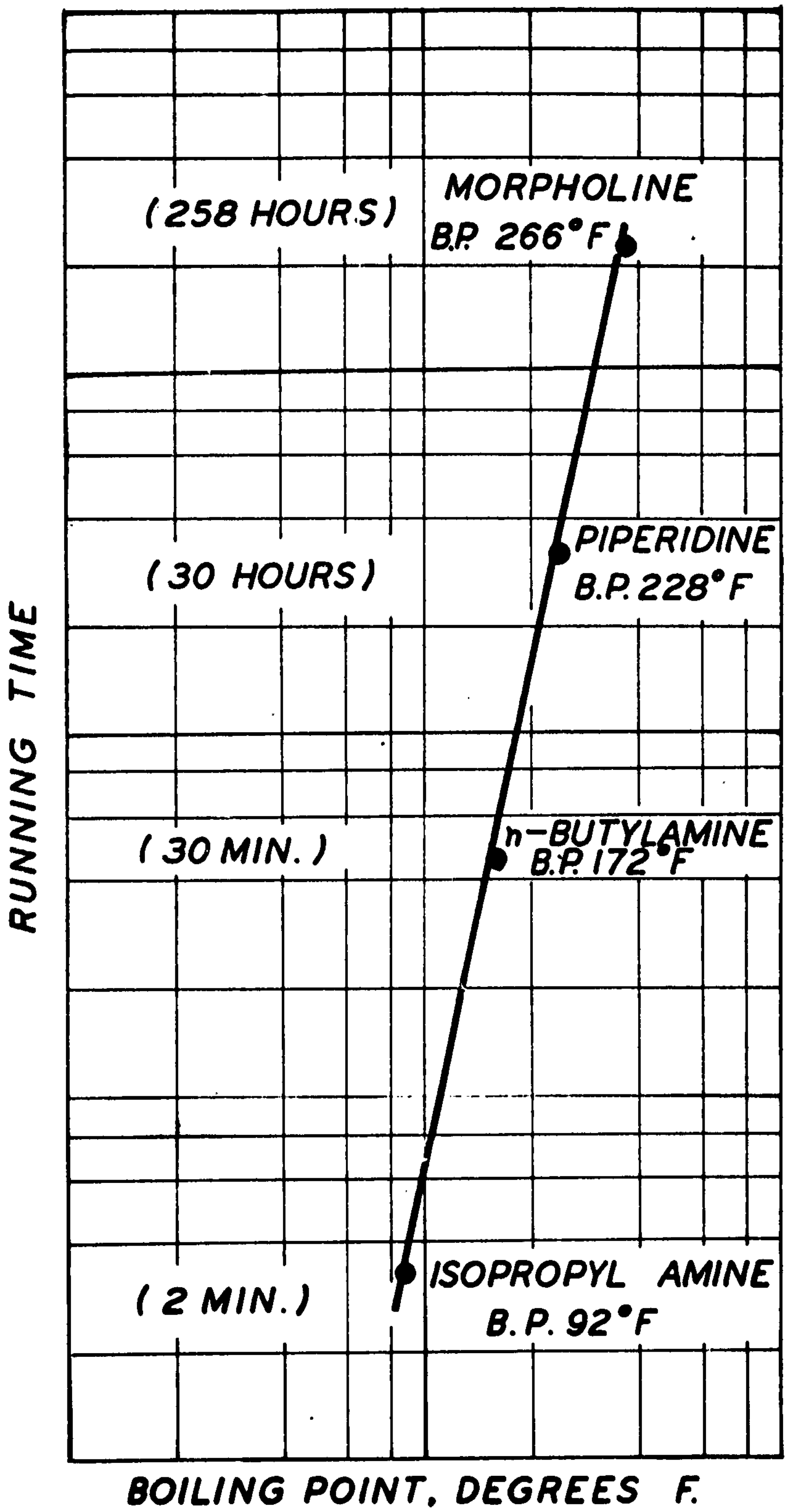
Apparatus: High Speed High Temperature Bearing Test Apparatus

Test Specimen: '204 Size Ball Bearing, AISI 52100 Balls and Races, Retainer AISI C1010

Speed: 10,000 RPM

Temperature: 250°F

Carrier Gas	Running Time Hours				
	Camphor	Cyclohexylamine Carbamate	Morpholine Carbamate	Naphthalene	Dicyclohexylamine Carbamate
O_2	---	---	0.1, 0	0, 0	---
He	0.1	---	41, 64	68, 50	---
Argon	7.0	0.1, 0.2	---	42	---
CO_2	0.1, 0.8	---	---	---	0.1, 0.3
N_2	123	148, 129	109, 406	309+	72+, 80+

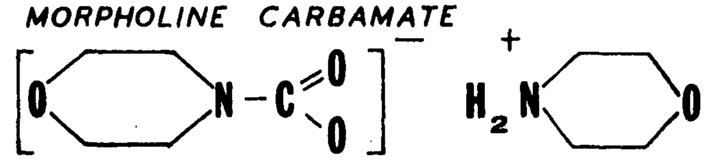


BOILING POINT (AMINE COMPOUNDS) VS RUNNING TIME
(CARBAMATE DERIVATIVES)

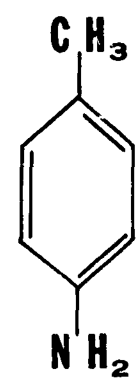
PLATE I

CHEMICAL STRUCTURE

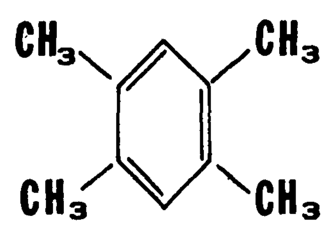
1. MORPHOLINE CARBAMATE



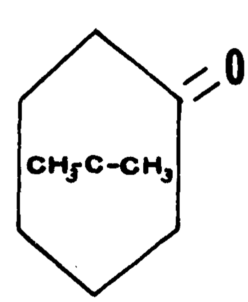
2. p-TOLUIDINE



3. 1,2,4,5 TETRAMETHYL BENZENE



4. CAMPHOR



CHEMICAL COMPOUNDS FOR VAPOR LUBRICATION

PLATE 2